Course Structure and Description

Machine Elements & Mechanisms I (ME&M-I)

PART I

- Introduction into the theory of Planar Mechanisms: Statics, Kinematics, Kinetostatics and Dynamics; Mechanisms with Bars, Screws, Gears and Cams;
- Introduction to Mechanical Engineering Design: **Springs** and Threaded Fasteners & Power Screws

PART II

MEM-II Subjects:
- Shafts
- Keys
- Bearings
- Friction assemblies

PART III

Mechanical transmissions:
- Gears
- V-belt Pulleys
- Couplings/clutches
- Friction drives

Chapter 1 (Machine elements) **Springs**

- Definitions, introduction
- Applications of springs
- Types of springs
- Classifications
- Spring performances
- Helical spring geometry
- Forces in springs

Brief history

Ancient time:

- Egyptians: lever, wedge (inclined plane), log roller – construction of pyramids;
- Mesopotamia: wheel and pulley (axle);
- Greeks: Arhimede from Siracusa (water screw), Archytas from Tarent (screw), Aristotel from Stagira (friction wheels and gears), Heron from Alexandria (syringe mechanism);
- Romans: military applications (catapults, wall scaling apparatus) and civil applications.

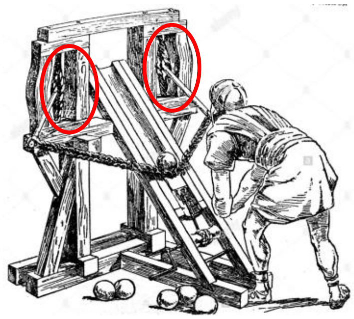
Modern time:

- Leonardo da Vinci, Galileo Galilei,
- Isaac Newton, James Watt,
- Leonhard Euler, Joseph-Louis Lagrange,
- Franz Reuleux, Robert Willis,
- Gaspard Monge, Jean Nicolas Pierre Hachette,
- Pafnuty Chebyshev, Ivan Ivanovichi Artobolevsky
- Henry Brown
- Kurt Hain, Richard Hartenberg and Jacques Denavit

Ancient using of springs (1)

Bow

Ancient using of springs (2)



Introduction

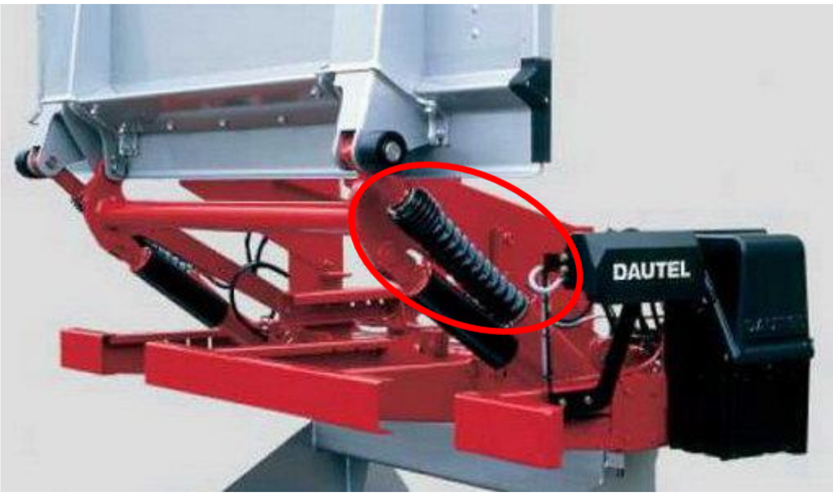
Spring is an elastic machine component able to deflect under load in a prescribed manner and to recover its initial shape when unloaded. Although most springs are mechanical, hydraulic and air springs are also obtainable.

Functions:

1. STORING ENERGY - to store energy and to restore it later, gradually or by shock: balancing mechanisms, clock motors, valves, test rigs for materials, etc.
2. DAMPING - to reduce the magnitude of the transmitted force due to impact or shock: railway carriages, aircraft landing gears, automobiles, artillery recoil systems, etc.
3. ALTERING VIBRATIONS - to alter the vibratory characteristics: coil-spring couplings, flexible mounting of motors, compressors, etc.
4. CONTROLLING - To apply load and to control motion: cam mechanisms to keep higher pair, in brakes & clutches, turnbuckles, etc.
5. MEASURING - to measure forces or moments: weight scales, spring dynamometers, pressure gauges, dial indicators, etc.

Balancing Mechanisms with Springs

Back loading/unloading Platform

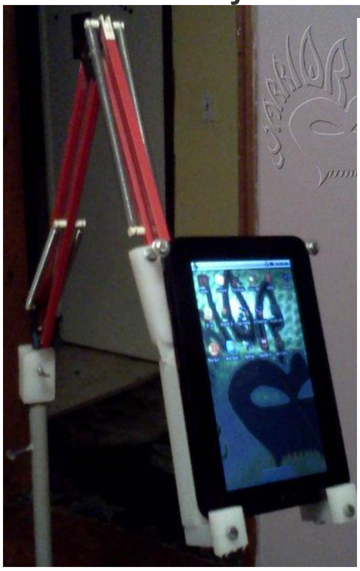


Balancing Mechanisms with Springs

Desk Lamps with Articulated Arms

Balancing Mechanisms with Springs

Adjustable Articulated Arms



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Balancing Mechanisms with Springs

Industrial Vacuum Cleaners

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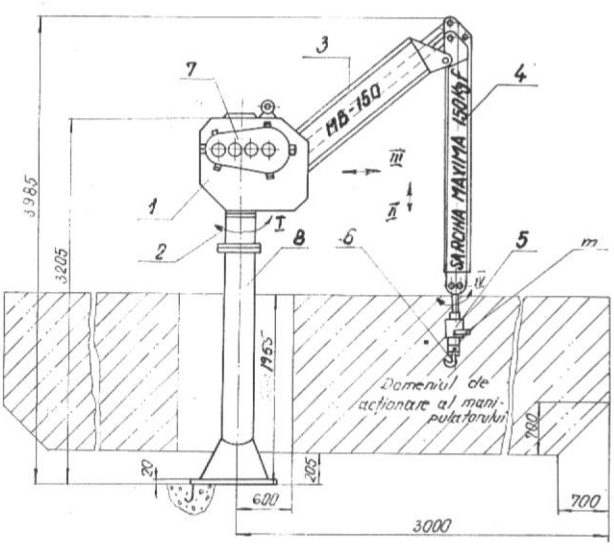
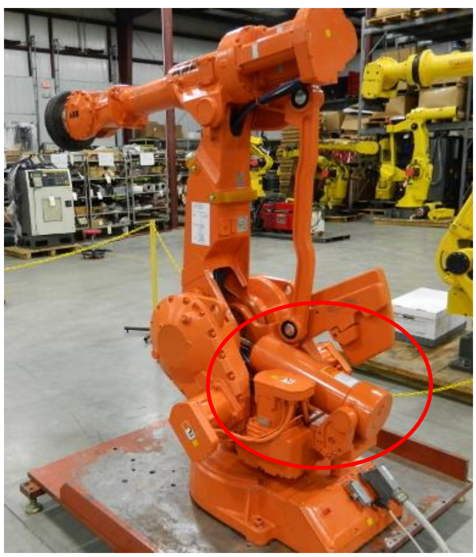
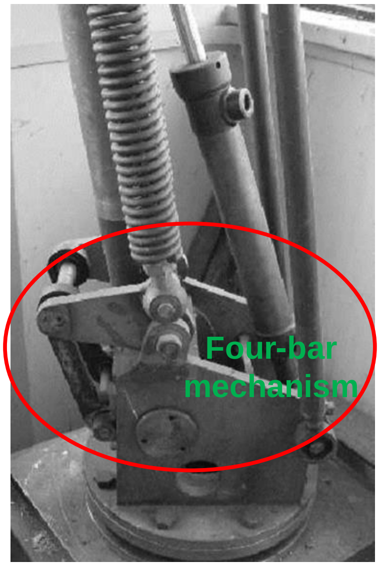
Balancing Mechanisms with Springs
Ergonomic Manipulators

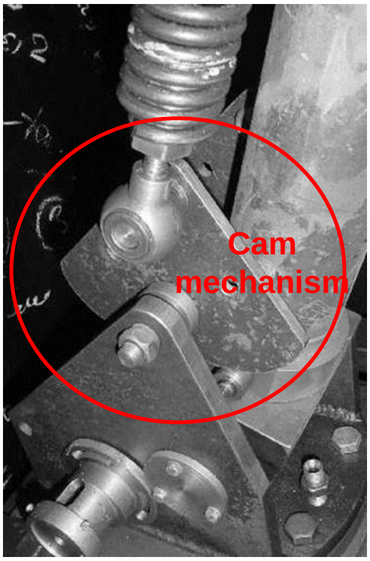


Balancing Mechanisms with Springs
Industrial Robots



Balancing Mechanisms with Springs

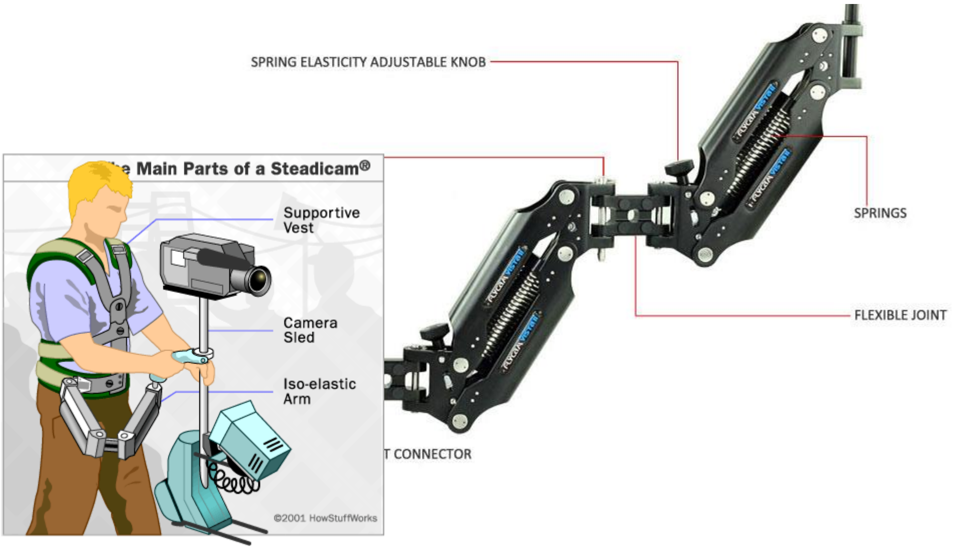




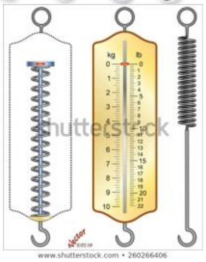
Experimental Models (left one in CG023 Lab)

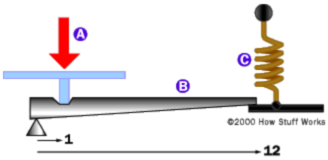
Balancing Mechanisms with Springs

Iso-elastic Arms used in Cinematography



Balancing Mechanisms with Springs
Weighting Scales





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Balancing Mechanisms with Springs
Lokomat rehabilitation system

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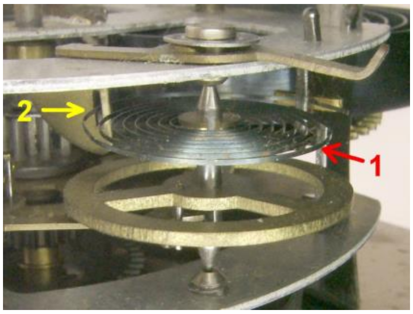
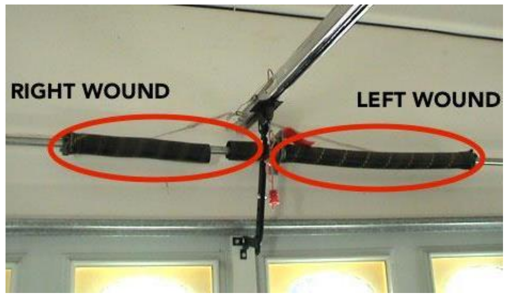
Balancing Mechanisms with Springs

Clocks and Garage door

The balance spring is a fine spiral or helical torsion spring used in mechanical watches, alarm clocks, kitchen timers, marine chronometers, and other timekeeping mechanisms to control the rate of oscillation of the balance wheel.



The torsion spring reacts to a torsion applied to the axis on which the spring is wound. Depending on the type of work they have to perform, torsion springs can be made with right-hand wind and with left-hand wind



Main types of springs

Helical Compression Spring

Helical Extension Spring

Conical Spring

Volute spring

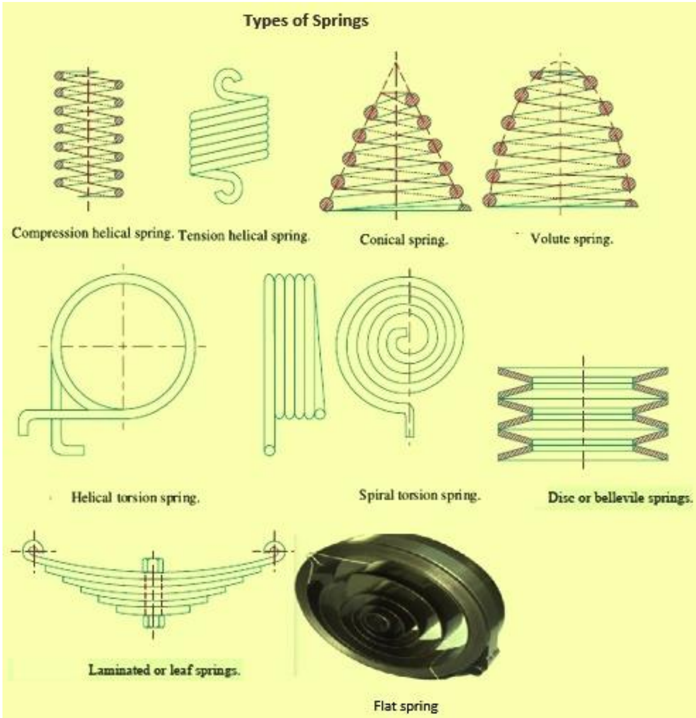
Torsion Spring

Laminated or Leaf Sp

Torsion bar

Disc or Belleville Spring

Ring spring

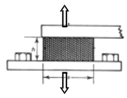
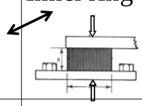
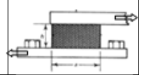


Classification criteria

- **Shape of the spring/coil** – helical, torsion bar, leaf, disk, ring, block, spiral, non-conventional
- **Type of the external load** – compression, extension, bending, torsion, shear
- **Type of the main stress inside spring** – compression, traction, bending, torsion, shear
- **Type of the material** – metallic, non-metallic
- **Shape of coil cross-section**– round, annular, rectangular, profiled
- **Spring Stiffness** (spring characteristic) – constant, variable (progressive/regressive)

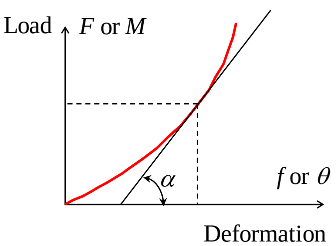
Classification criteria

MAIN STRESS INSIDE SPRING (INTERNAL LOAD)

EXTERNAL LOADING OF SPRING	Traction	Compres sion	Bending	Torsion	Shear
Traction					
Compression	Outer ring 	Inner ring 			
Bending					
Torsion					
Shear					

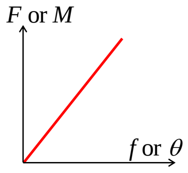
Spring Performances (1)

Spring rate (spring characteristic)

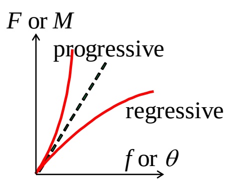


$$k = \frac{\mathrm{d}\boldsymbol{F}}{\mathrm{d}\,f} \qquad k = \frac{\mathrm{d}\boldsymbol{M}}{\mathrm{d}\,\theta}$$

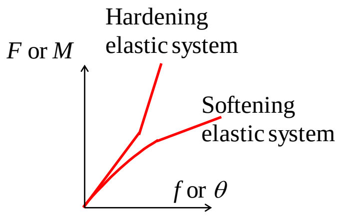
$\alpha = \arctan(k)$



a) linear

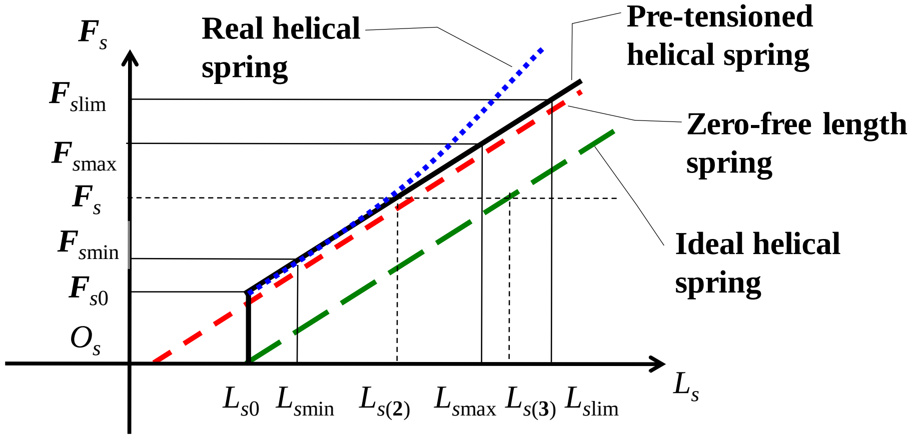


b) non-linear



c) composed

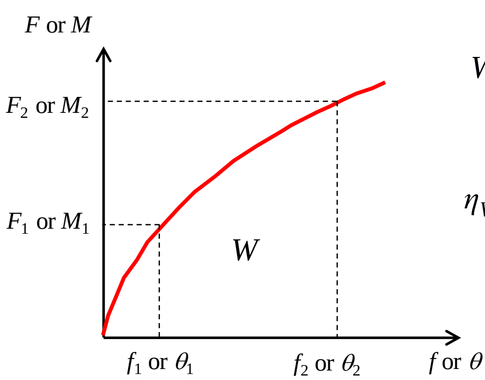
Helical spring characteristics



Variation diagrams of the elastic forces of the helical springs for extension with respect to the length of the spring

Spring Performances (2)

Specific energy factor (utilization factor)



$$W = \int_{f_1}^{f_2} \boldsymbol{F}\,\mathrm{d}\,f \qquad W = \int_{\theta_1}^{\theta_2} \boldsymbol{M}\,\mathrm{d}\,\theta$$

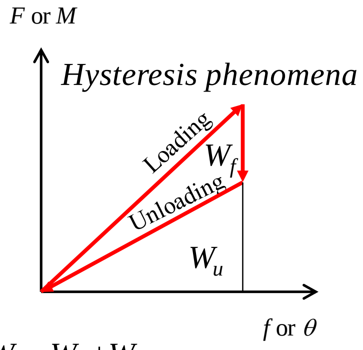
$$\eta_W = \frac{W}{V\dfrac{\sigma_{\max}^2}{2E}} \qquad \eta_W = \frac{W}{V\dfrac{\tau_{\max}^2}{2G}}$$

V – volume of spring

In case of linear characteristics $W = \frac{1}{2} F\,\Delta l = \frac{1}{2}\sigma A \varepsilon\, l = \frac{1}{2}\sigma A\,\frac{\sigma}{E} l = \frac{V\sigma^2}{2E}$

Spring Performances (3)

Spring efficiency



$$W = W_f + W_u$$

W – energy consumed at loading
W_f – energy consumed due to friction
W_u – energy recovered at unloading

$$\eta_s = \frac{W_u}{W} \quad \text{spring efficiency}$$

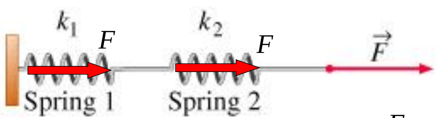
$$W_u = W - W_f$$

$$\eta_s = 1 - \frac{W_f}{W} = 1 - \eta_d$$

$$\eta_d = \frac{W_f}{W} \quad \text{damping efficiency}$$

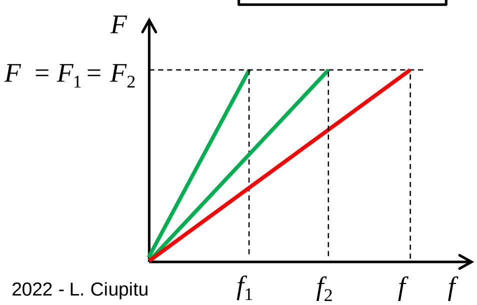
Spring Grouping

Series connection



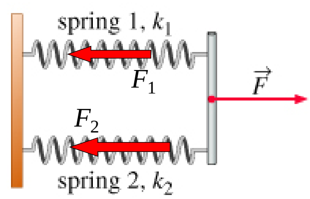
$f = f_1 + f_2$ $\quad F = F_1 = F_2$

$$\frac{F}{k_e} = \frac{F_1}{k_1} + \frac{F_2}{k_2} \qquad \boxed{\frac{1}{k_e} = \frac{1}{k_1} + \frac{1}{k_2}}$$



Parallel connection

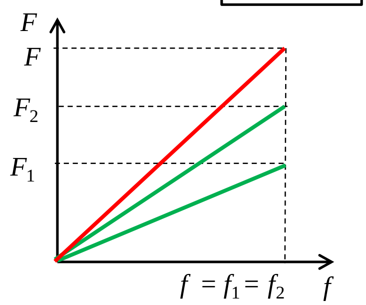
$F_1 = k_1 f_1$
$F_2 = k_2 f_2$
$F = k_e f$



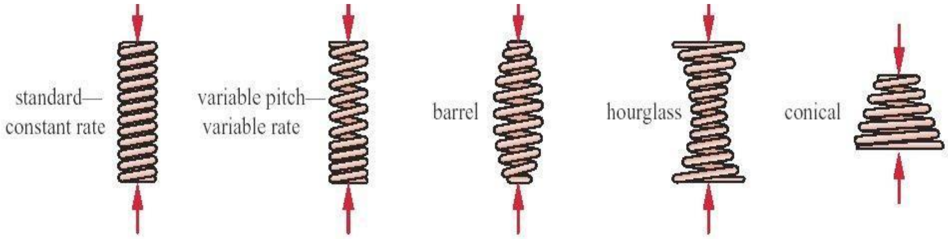
$f = f_1 = f_2$

$F = F_1 + F_2$

$k_e f = k_1 f_1 + k_2 f_2$ $\quad \boxed{k_e = k_1 + k_2}$



Helical Spring Types (1)

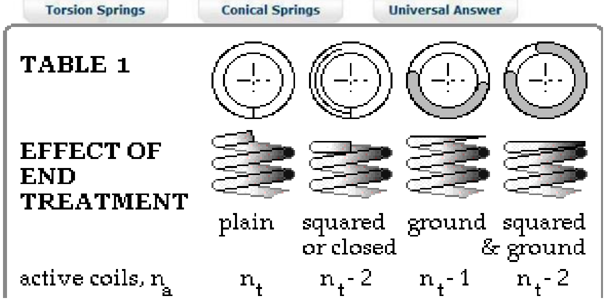


Helical extension spring

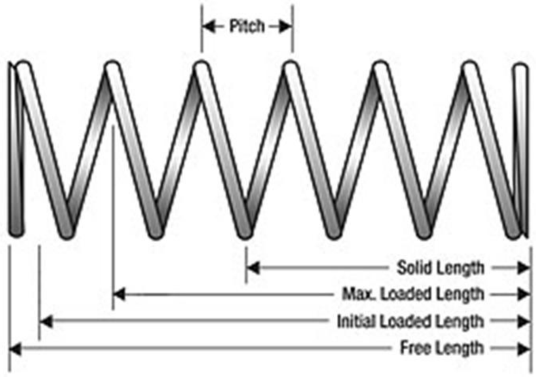
Drawbar spring

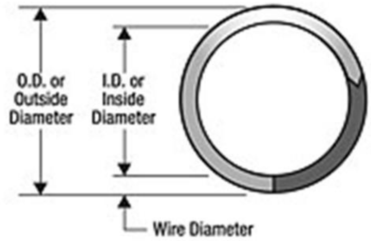
Torsion spring

Helical Spring Types (2)



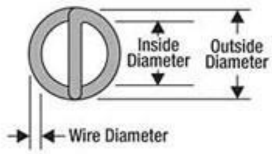
Helical Spring Geometry

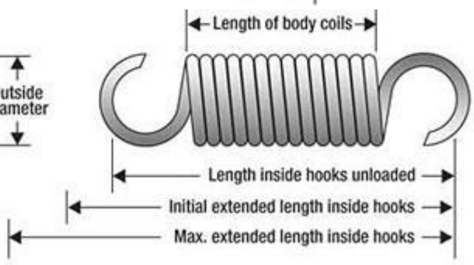


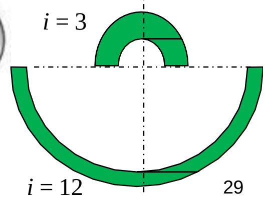


Spring index $i = \frac{D_m}{d}$

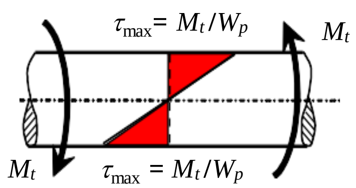
$i = 3 \ldots 12\,(16)$

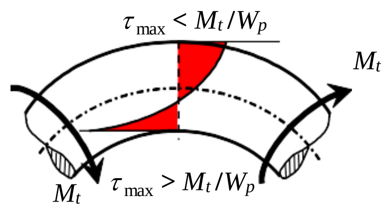


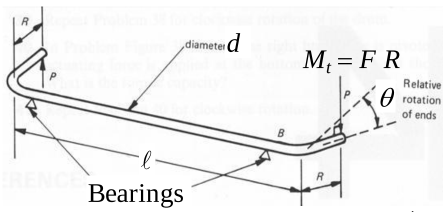




Torsion bar versus helical coil







$M_t = k\,\theta \qquad k = \frac{G\, I_p}{\ell} \qquad I_p = \frac{\pi\, d^4}{32}$

$W_p = \frac{\pi\, d^3}{16} \qquad \eta_W = \frac{1}{2}$

Inner part of coil is a stress concentrator

Curvature correction by a correction factor

$$\tau_{max} = K_X \frac{8\, F\, i}{\pi\, d^2} \qquad \begin{cases} K_W - \text{Wahl} \\ K_B - \text{Bergstrasser} \\ K_M - \text{Manea} \end{cases}$$

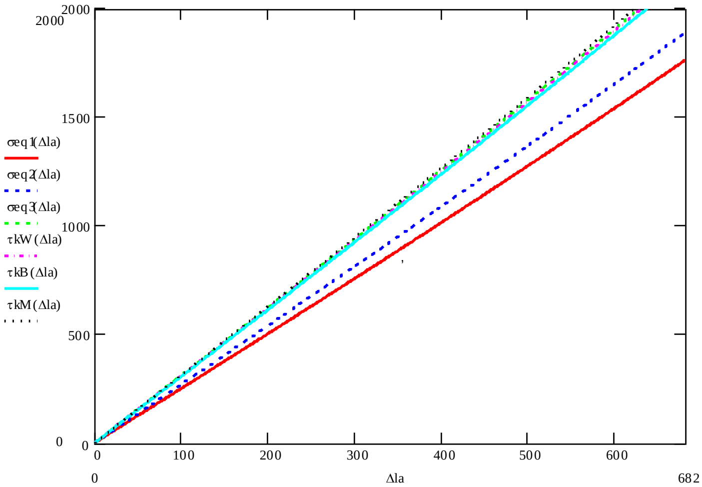
$$\boxed{k = \frac{G\, d}{8\, i^3\, n_a}} \qquad n_t = n_a + n_r$$

n_t – number of total coils

n_a – number of active coils

n_r – number of reduced coils

Stresses corresponding to different failure theories and different correction factors



$$\sigma_{eq1} = \sqrt{\sigma^2 + 2.6\tau^2}$$

$$\sigma_{eq2} = \sqrt{\sigma^2 + 3\tau^2}$$

$$\sigma_{eq3} = \sqrt{\sigma^2 + 4\tau^2}$$

$$k_W = \frac{4i-1}{4i-4} + \frac{0.615}{i}$$

$$k_B = \frac{i+0.5}{i-0.75}$$

$$k_M = 1 + \frac{1.6}{i}$$

Conclusions

- There are many kind and shapes of springs:
  - helical at compression, traction, torsion;
  - spiral, conical, volute etc.
  - disk, ring, leaf etc.
- Most common and used spring is helical spring
- Spring stiffness characteristics are constant or variable
- Hysteresis phenomena is present at springs with many elements between the friction occurs
- Pre-tensioned helical springs could be made by special manufacturing technics.